Doppler Observations of the Impact of Comet S1.9 Fragment A

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Abstract. In this paper we present an attempt to detect Doppler effect on Jupiter during the impact of the fragment A of the comet, Shoemaker-Levy 9. We give a short description of the technique used to observe the impact, then present the observations and finally a theoretical analysis and interpretation. The instrumentation used is an advanced and more sensitive version of the Magneto-Optical Filter (normally used in Helioseismology to detect global oscillations of the Sun) and a 40 cm aperture telescope. The observed signal consists of a double peak transient that could be interpreted as the signature of an expanding perturbation.

Introduction

For the past several years, we have been observing global solar oscillations manifested as a doppler shift of the sodium D absorption lines. The line-of-sight velocity variations are measured using a Magneto Optical Filter (MOF) in which two extremely narrow passbands are switched sequentially between two wavelengths. The difference in intensity in the two wings of the solar line profile yields the instantaneous velocity. Sunlight is sufficiently intense that no telescope is needed, the sun being tracked continuously with a simple heliostat.

We have also been considering other applications of the MOF to planetary and stellar astronomy, e.g., the possible detection of global oscillations of Jupiter's atmosphere whose existence would initiate "seismological" studies of the deep atmosphere. Prompted by the unusual opportunity posed by the Shoemaker-Levy fragments, we decided to attempt doppler measurements of Jupiter near the times of impact.

Observations were attempted each night of the week of the Shoemaker-Levy impacts. Unfortunately, cloudy weather precluded observations for all but event A at which time a signal was seen unlike any other detected while observing Jupiter. In the following, we describe the instrumentation, present the observational data and discuss the probable association of this signal with the Shoemaker-Levy impact.

The Experimental Setup

The Magneto-Optical Filter (MOF), developed by A. Cacciani and used mainly in solar physics, is discussed in several papers (e.g., Cacciani & Fofi, 1979, Cacciani et al., 1994, Rhodes et al., 1988, 1990). Its basic characteristics are high-transmission (≈ 50%), high spectral resolution, large field of view, absolute spectral reference and stability. It consists of a glass cell containing sodium vapor in a longitudinal kiloGauss magnetic field interposed between two crossed linear polarizers. With suitable choices of magnetic field and temperature we obtain two bandpasses, 35 mÅ wide and separated by 150 mÅ, for each of the sodium D-lines at 5890 and 5896 mÅ. A second cell in a magnetic field of 3000 G, called a Wing Selector (WS), selects only one of the two bandpasses at will.

As a demonstration of performance, figure 1 is an observing run made at JPL on the sun-as-a-star to detect the relative Sun-Earth velocity. It was taken on December 1, 1994 using an MOF identical to the one used for Jupiter, with the exception that an analog signal processor is used instead of a photon counting system. The sinusoidal trend is due to the earth rotation. In the morning, the system is approaching the sun, while in the evening, it is receding from it. The small oscillatory signal visible on top of the sinusoid is due to the well-known 5-minute band solar oscillations. Their rms amplitude is ≈ 1 m/s and the noise is < 10 cm/s.

Our configuration is an advanced version of the single cell MOF used by Schmider et al. (199 1) at Jupiter since sampling two wavelengths along the line profile permits a better estimate of the velocity in the jovian atmosphere.

Because of the anticipated weakness of the radiation in the vicinity of the sodium D-line after reflection from Jupiter, steps were taken to enhance the signal. The usual analog electronics were replaced with a photomultiplier tube followed by a photon counting circuitry. A fairly small aperture telescope was available to us, the 40 cm "Cooke" telescope of the Osservatorio Astronomic "V. Cerulli" of Teramo-Italy. It was used with the instrumental set-up shown in figure 2. The phototube was an RCA C3 1034 with a quantum efficiency of 0.1 The two transmission bands of the filter were alternated every 3 seconds by a computer-controlled lambda/4 Liquid Crystal (LC) retardation plate and the counts recorded in the two separate buffers.

During all the observing runs, the temperatures of the cells were kept stable within 0.4 C. The resulting fluctuation in the photon counts was much less than the statistical photon noise. Very good guiding stability was achieved by using a CCD camera directly in the reference beam (see figure 2). Figure 3 shows the transit of Jupiter across the field of view of the MOF.

Observations

The velocity field on the visible surface of Jupiter modifies the shape of the line profiles and the perturbed intensities are detected by our system at the transmitted wavelengths (two for each sodium D-line). The intensity profiles of the solar Fraunhofer lines are reflected by each point of the jovian surface with a Doppler shift depending on the local velocity, projected along the line of sight. As a result of the planet's rotation, the "jovian" lines (integrated over the full disk) show a fairly large Doppler broadening. Moreover, they are also Doppler-shifted by the relative orbital motion between Jupiter and Earth that in July 1994 amounts to about 530 mÅ toward the red. "l'he jovian sodium D-line and the corresponding position of the MOF transmission profile, (as in Jul y 1994) are shown in figure 4. The transmitted light is larger for the blue band (B) than for the red band (R) as is observed (figure 5). Note that the region of the impact, close to the terminator (dayline), reflects the solar Na lines at wavelengths between B and R (figure 4).

Assuming a value of -1.60 for visual apparent magnitude of Jupiter and taking into account the total transmission of the Earth atmosphere and the optics, a photon flux of about 15000 s^{-1} on each band of the filter is obtained,

Figure 5 shows the data taken soon after the impact of fragment A on July 16. During the whole run lasting 2.5 hours the noise level of the signal remains the same with the exception of a double peaked structure, 5 sigma above the noise, only visible in the blue band B around the time of the impacts as given by Chodas (1994).

Tentative Theoretical Prediction

The most important aspect of our observation is the time evolution of the measured signal. In order to analyze the signal we consider the combined velocity field generated by a wave-like perturbation and Jupiter's rotation. This overall velocity field corresponds to a "Doppler displacement field" useful in computing the perturbed jovian spectral line profiles.

The aim of the analysis is to estimate the amplitude of the normalized signal (B-R)/(B+R) at any time, starting from the instant of the impact, at the position provided by Chodas et al. (1994). The impact generates pressure, gravity and shock waves in addition to an expanding plume. In a pressure wave, the particle displacements are tangent to the surface and the velocity component along the line of sight is maximum at the limb. Here also the presence of the terminator helps discriminate between the positive and negative velocity portions of a wave. This effect is essential to explain the transient feature that appears both in the anticipated and observed signal. Indeed, once the complete wavefront becomes fully visible as it crosses the dayline, its integrated effect produces only a minor residual bias while the transient signal returns to nearly the previous level. In a gravity wave, the displacements are transverse to the line of sight and their velocity components along the line of sight are maximum at the disk center where, however, both positive and negative portions of the wave are simultaneously visible.

To render the analysis quantitative, we need a wave-like velocity profile made up of a single positive front followed by a single negative front. The velocity v can be written as:

$$v(r, t) = A \cdot (|r - r_0| - D(t)) \cdot \exp\left[-\left(\frac{|r - r_0| - D(t)}{\delta}\right)^2\right] \qquad (1)$$

where r. is the position vector of the center of the expanding wave, D is the radius of the circular wave increasing linearly with time and δ is a parameter describing its "wavelength", We have adopted for it a value of 50 km, large enough to allow the dayline penumbra to discriminate between the positive and the negative portion of the wave. The profile in equation (1) meets the hydrodynamical condition that the time-integral of the pressure variation is null when the integral is calculated at a generic fixed point crossed by the wave.

The results of applying this preliminary model (more accurate calculations will be given in a future paper) are the following (figure **6):**

a) A double-peak structure, whose amplitude is a function of particles velocity, is always present in the signals provided by the two bands of the MOF, even if it is much smaller than observed.

b) There is also a difference between the levels of the signals before and after the event. This is because the positive and negative portion of the wave do not produce in general the same variation (opposite in sign) and do not cancel one another.

c) The B signal can be different from the R signal.

The double peak marks the passage at the dayline of a circular perturbation as it is carried around by the planet rotation. To clarify this point we must distinguish between the motion of the wave toward the observer at the leading edge and away from the observer at the trailing edge. However, what is being observed is the. motion of the gas which is toward the observer and then away on both the leading and trailing edges. Therefore, the pulses still have the same direction (sign) as observed.

The Data of the Impact A

The results of the calculations discussed above are apparently in qualitative agreement with our observations. Figure 5 shows a portion of our 2.5h run on July 16, 1994 where is visible a double peak transient with temporal lag between peaks of 66s. Assuming 8.6 Km/s for the surface speed due to Jupiter rotation at the latitude of -44°, it could represent a circular expanding perturbation of -570 Km diameter at the time of our observations.

The amplitude of the peaks in the blue band (B) is at least 8 times larger than in the red (R) and there is no macroscopic difference between the pre-impact and the post-impact photon counting rate. This puts constraints to the (material) particles speed when they are crossed by the perturbation: the model becomes consistent with the observations if the particle velocity is in the range of 5-20 Km/s.

From the diameter of the wave and the time elapsed between the impact and the passage of its center it would be possible to infer the speed of the. perturbation (wave). However our clock read 19h 58m 26s GMT when the first pulse was detected at its maximum. The second pulse appeared at 19:59:32. This put the event even earlier than the time of impact predicted by Chodas et al. 19:59:42. This apparent timing discrepancy needs to be investigated further.

Conclusions

During the SL9, fragment A, impact on Jupiter we have used a Magneto-Optical Filter at 40 cm telescope to test its performance as an instrument for planetary and stellar seismology. We have measured the photon flux through the two MOF narrow passbands and checked the difference between them due to the orbital motions. After the impact we have noticed two distinct time variations that are not instrumental. Our analysis reveals that the observations are qualitatively similar to the effect of traveling perturbations crossing the border line between day and night,

We infer a particle speed of about 13 +/- 8 Km/s amplitude. Finally, we suggest that this kind of measurement be continued not only on Jupiter but also on other variable stellar objects.

At this time, we cannot be certain that our signals are caused by S-L nor can we exclude this possibility. Future comparisons with other observations by other investigators and additional physical modeling that will inevitably follow should lead to a definite conclusion.

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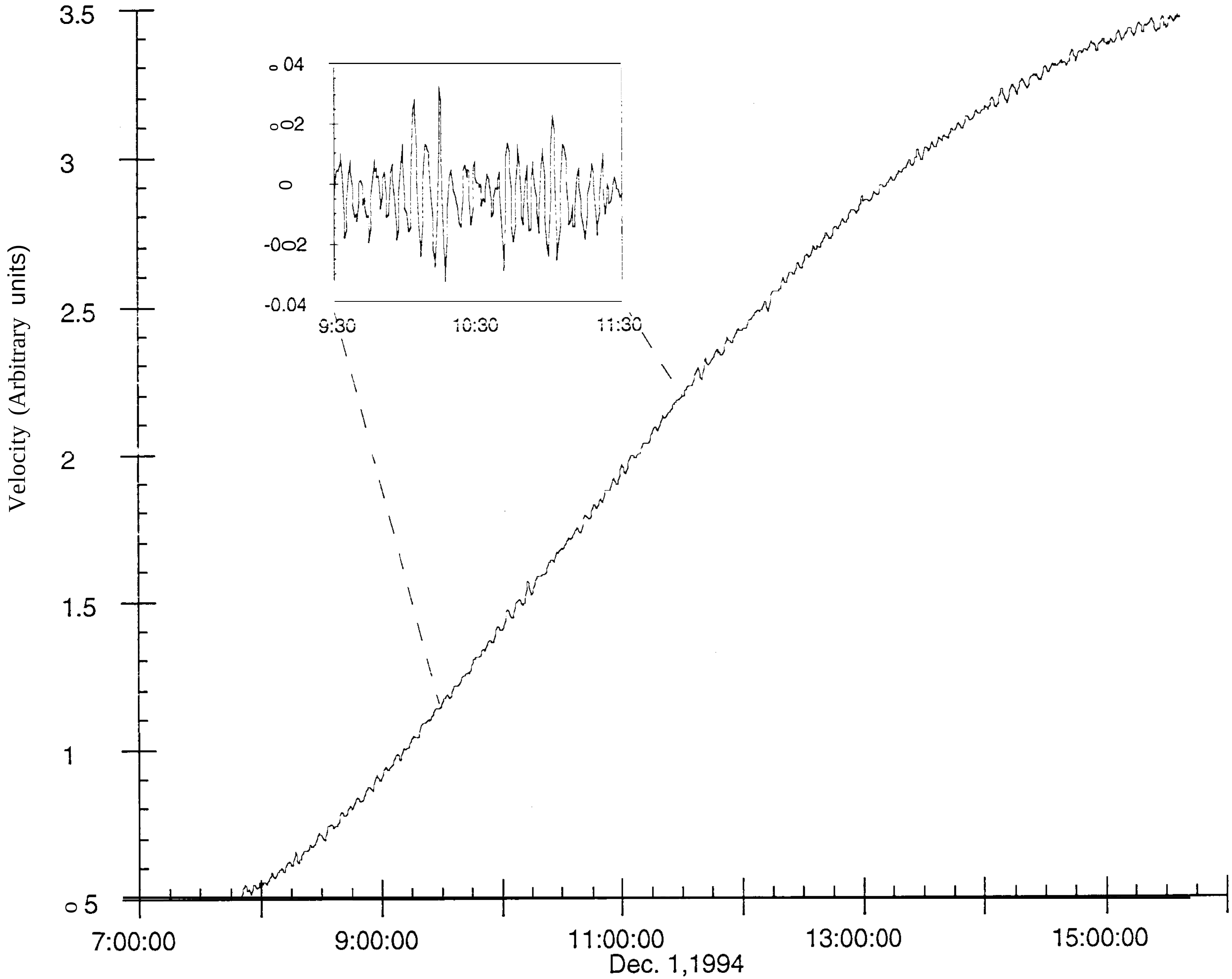

Figure 1: Relative Sun-Earth Velocity Detected at JPL using the Magneto Optical Filter

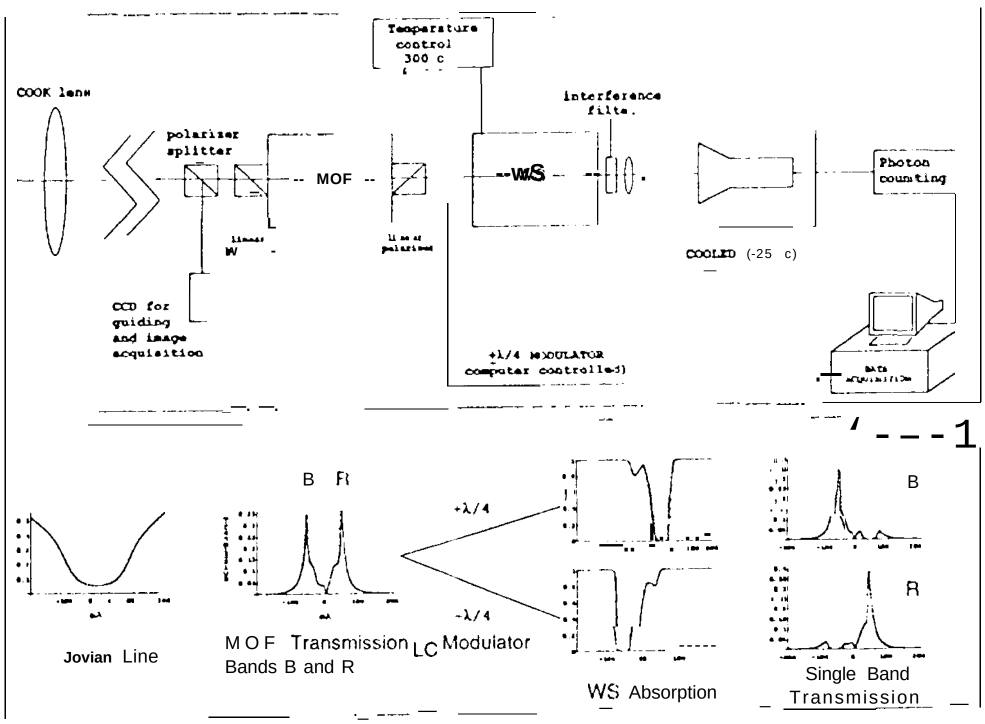

Fig 2. The experimental setup (top half) and the spectral analysis performed on the Jovian Na line.

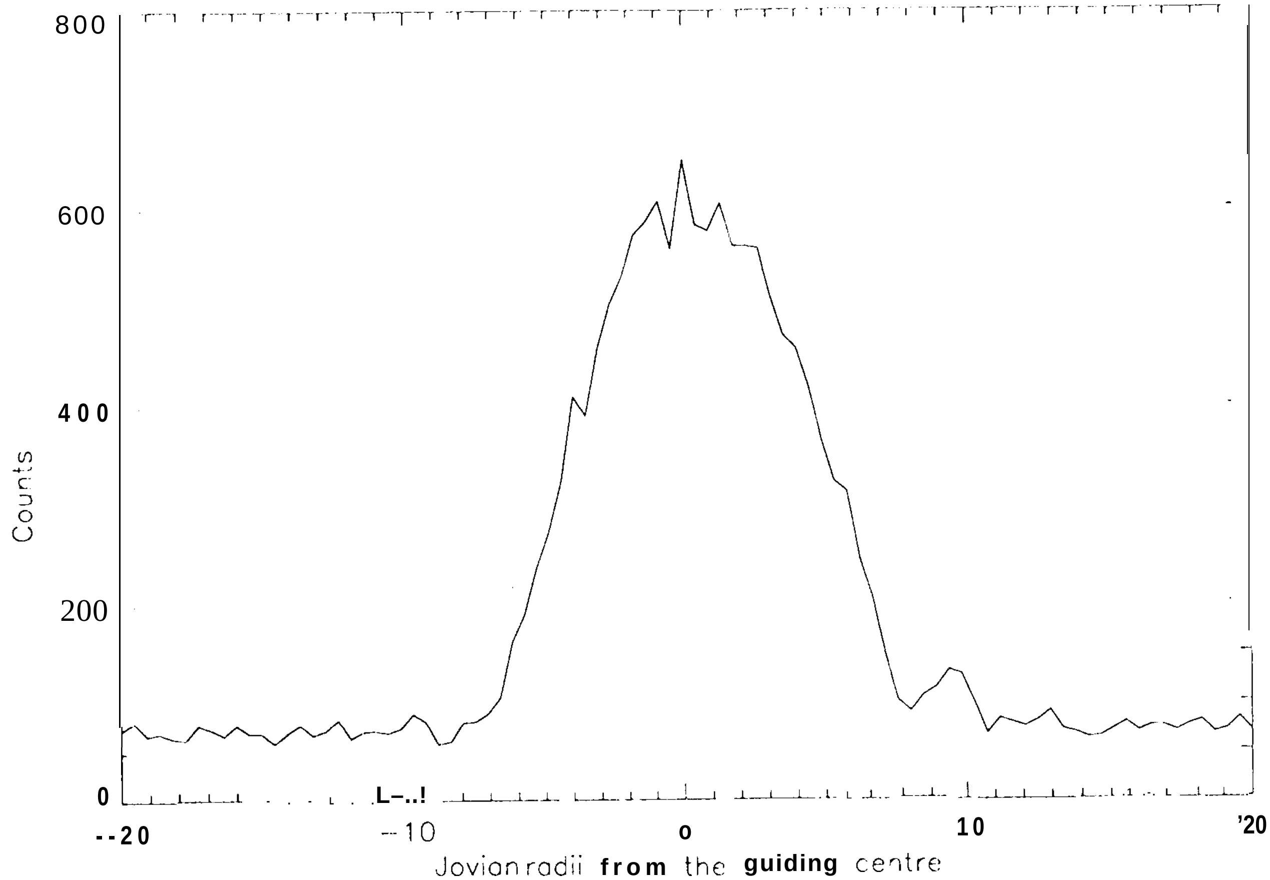

Fig 3. Transit of Jupiter across the field of view of the MOF

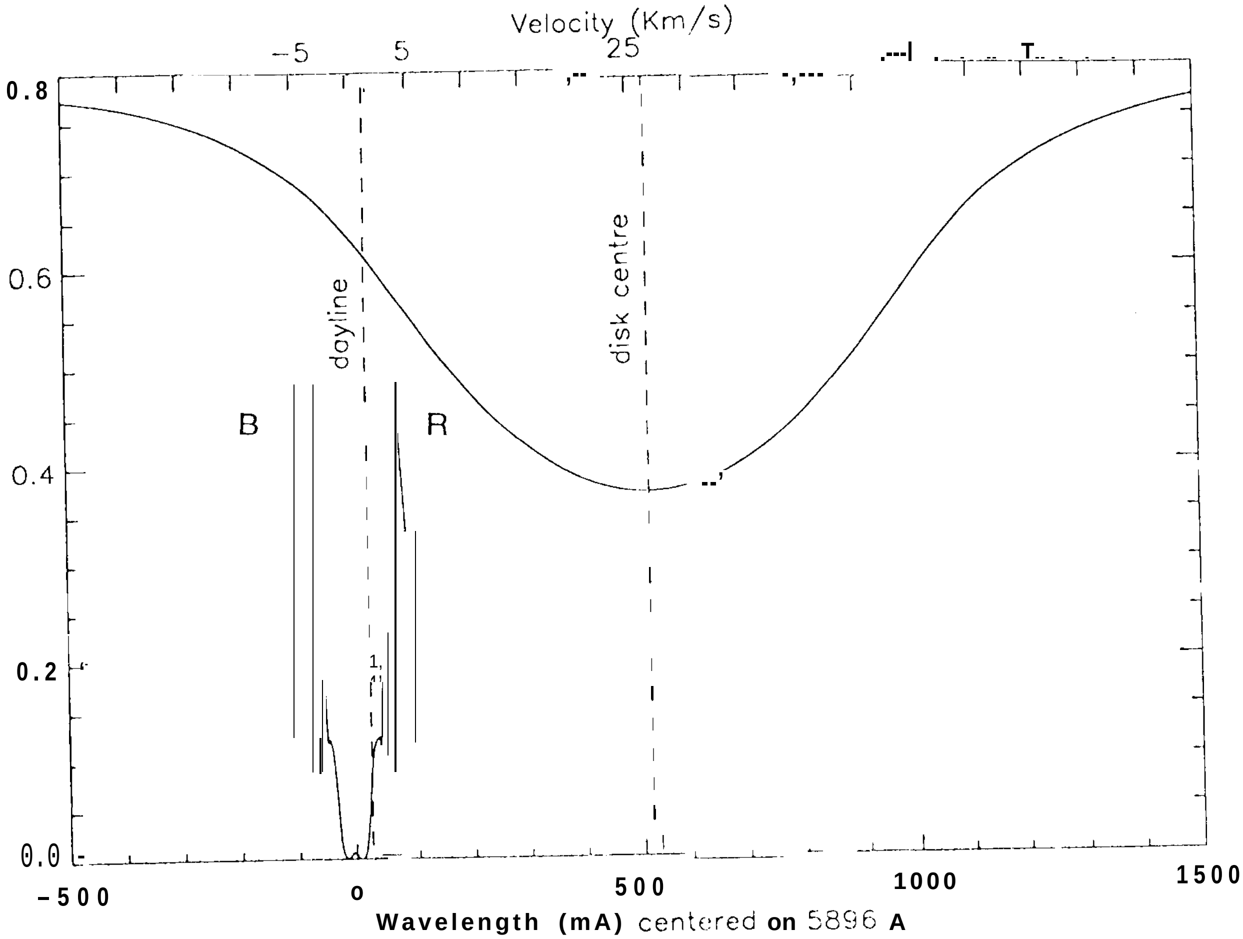

Fig 4. Relative spectral position of the Jovian Na line and the transmission bands (B and R) of the MOF.

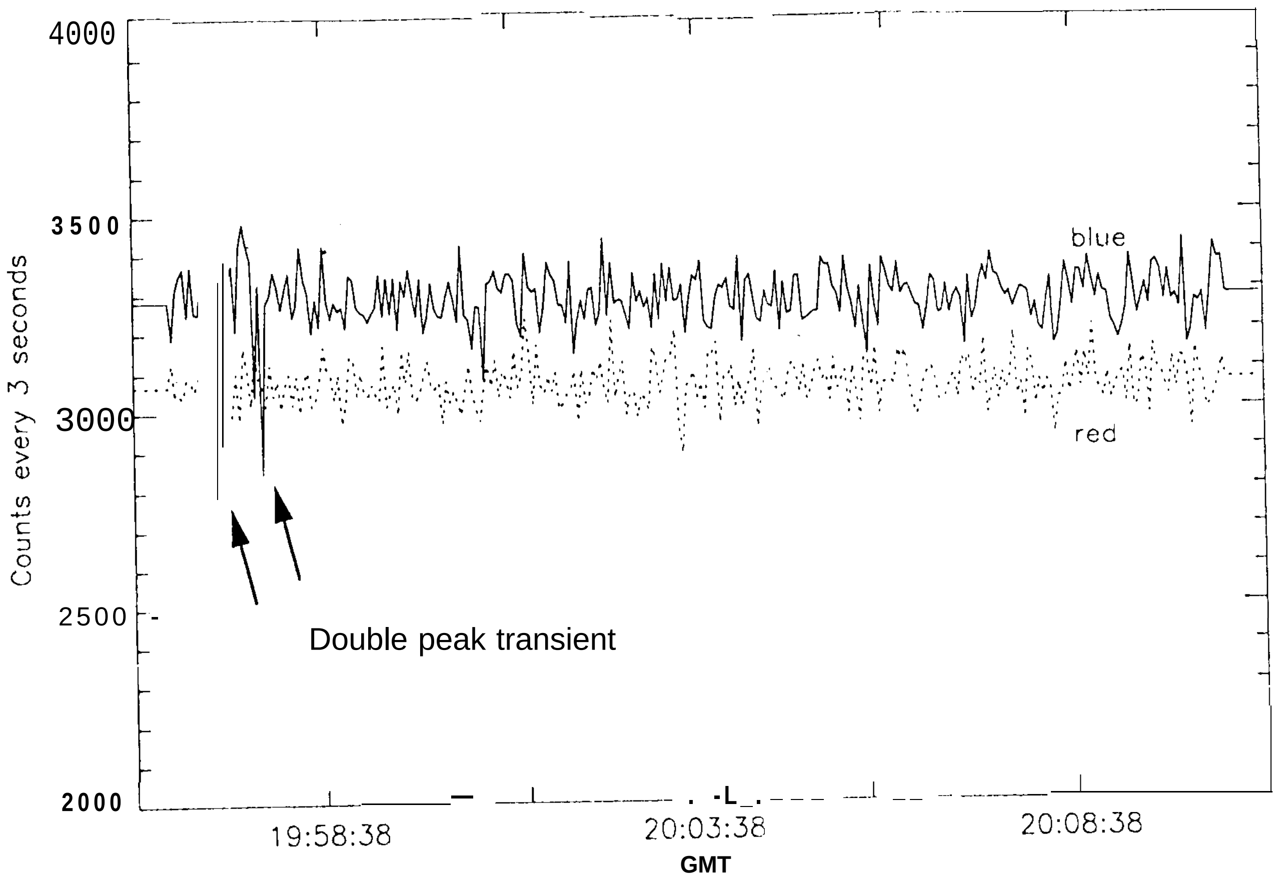

Fig 5. data taken with the MOF around the time of impact A. A double peak transient, 5σ above the noise level, in visible at our clock times 19:58:26 and 19:59:32. It may represent a ring of expanding perturbation 570 Km in diameter.

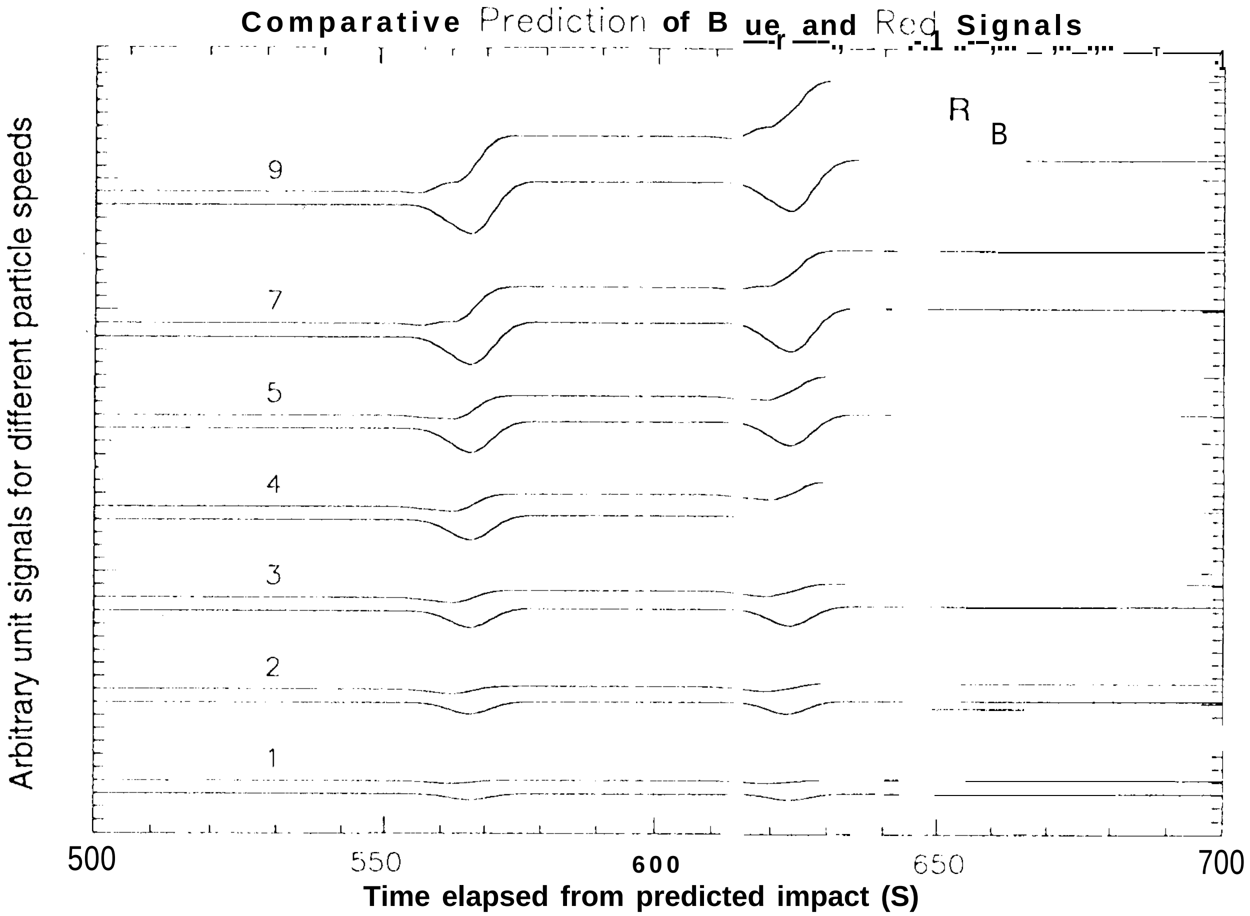

Fig 6. Expected theoretical signal from the passage at the terminator of an expanding circular perturbation.